Contents


```
%-----------------------------------------------
% AER 715 Avionics and Systems
% Lab 3 - Flight Control - Estimation of Model Parameters and Simulation
% Sharvani Yadav: 501108658
% Daniel Mielnik: 501118927
%----------------------------------------------- %
```

Introduction

This laboratory experiment aims to simulate and analyze the dynamics of a three-degree-of-freedom

```
%(3-DOF) helicopter. The helicopter's body is positioned at one end of the apparatus, with a brass
%counterweight at the opposite end, both connected to a pivot point. A pair of three-blade propellers,
%powered by a brushed DC motor, generates thrust, while the counterweight helps balance the force needed
%to lift the helicopter body. To model the helicopter's altitude, its pitch axis is mechanically fixed,
%and angles are measured using encoders. In this virtual environment, an analytical model of the helicopter
%is examined, with parameters based on experimental data. The encoder signals and motor power from the amplifier
%are transmitted through a slip ring to a data acquisition board, enabling comprehensive analysis of the helicopter's dynamics.
%
```

Post Lab Exercises –

```
clear all;
clc;
```

Constants for Heli 4

```
Mh = 1.450; % Mass of Heli Body (kg)
Mc = 1.918; % Mass of CW (kg)
La = 25.75/39.37; % Distance from Pivot to Helecopter body center (m)
Lb = 18.5/39.37; % Distance from Pivot to conterweight center (m)
Lh = 6.933; % Distance from pitch axis to rotor center (m)
Kf = 0.140; % Motor-Prop Force Constant (N/V)
Krt = 0.0027; % Motor-Prop Torque Constant (Nm/V)
epsilon = -26:1:30; % Elevation Range (Deg)
epsilon_0 = -25.75; % Elevation Start (Deg)
lambda = 0:1:360; % Travel Range (Deg)
g = 9.81; % Gravity constant (m/s^2)
Wh = Mh*g; % Weight of Heli Body (N)
Wc = Mc*g; % Weight of CW (N)
```

Question 1

```
Je = (Mh * La^2) + (Mc * Lb^2) % Elevation Axis (kg-m^2)
```

```
Je =

    1.0438
```

Question 2

```
epsilon_dd = 0;
Tg = Lb*Wc - La*Wh;
Ft = (Je*epsilon_dd - Tg)/La; % Lift force (N) required to achieve steady level flight
fprintf('The value of lift force required to achieve steady level flight is %f N \n', Ft)
```

```
The value of lift force required to achieve steady level flight is 0.706510 N
```

Question 3

```
Vsum = Ft/Kf; % Velocity required to keep helicopter at steady level flight (m/s)
fprintf('The value of Velocity required to keep helicopter at steady level flight is %f m/s \n', Vsum)

%The experimental value closely matches the analytically derived value.
%A slight discrepancy arises from the helicopter's weight fluctuating before
%stabilizing, which alters the overall measurement.
```

```
The value of Velocity required to keep helicopter at steady level flight is 5.046503 m/s
```

Question 4

```
G4_elev1 = tf(La*Kf, [Je, 0, 0]) % G elev transfer function

% The resulting transfer function is a second-order system with a numerator of 0.09157 and
% a denominator of 1.044s^2. This implies that the system has two poles at the origin,
% making it an unstable system. Since there are no first-order or constant terms in the denominator,
% the system behaves as a double integrator, meaning it will have an unbounded response to a step input.

% In terms of control system dynamics, this transfer function lacks both damping and oscillatory
% behavior. The system's output will continuously increase over time when a constant input is applied,
% showing that it has no stability or settling tendencies. The system essentially amplifies the input
% without providing any stabilization, as indicated by the two poles at the origin.
```

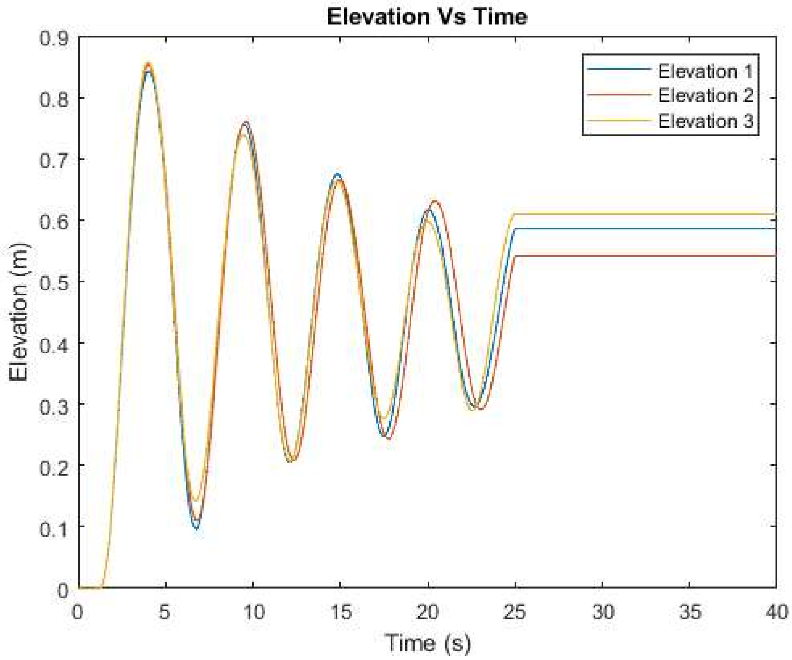
```
G4_elev1 =

   0.09157
  ---------
  1.044 s^2

Continuous-time transfer function.
```

Question 5

```
load elevationData1.mat
load elevationData2.mat
load elevationData3.mat

time = elev1(1, 1:end);

v1 = elev1(2, 1:end);
v2 = elev2(2, 1:end);
v3 = elev3(2, 1:end);

e1 = elev1(3, 1:end);
e2 = elev2(3, 1:end);
e3 = elev3(3, 1:end);

figure(1)
```

```
plot(time, e1, time, e2, time, e3)
title('Elevation Vs Time')
xlabel('Time (s)')
ylabel('Elevation (m)')
legend('Elevation 1', 'Elevation 2', 'Elevation 3')

data1 = iddata(transpose(e1), transpose(v1), 0.01);
data2 = iddata(transpose(e2), transpose(v2), 0.01);
data3 = iddata(transpose(e3), transpose(v3), 0.01);

mergedData = merge(data1, data2, data3);

G4_elev2 = tfest(mergedData, 2, 0);
G4_elev3 = tfest(mergedData, 3, 0);

[num1, denom1] = tfdata(G4_elev1, 'v')
[num2, denom2] = tfdata(G4_elev2, 'v')
[num3, denom3] = tfdata(G4_elev3, 'v')

% The output for the first-order system (G4_elev1):
% Numerator: 0.0916, Denominator: 1.0438
% This transfer function represents a second-order system with two poles at the origin.
% This configuration implies that the system is unstable, as it has no damping or dynamic behavior.
% The system response will grow indefinitely for any sustained input, making it highly sensitive
% and prone to instability.

% The second-order system (G4_elev2):
% Numerator: [0 0 0.0294]
% Denominator: [1.0000 0.1538 1.3288]
% The second-order system introduces two poles, leading to oscillatory behavior.
% The small coefficient on the s-term (0.1538) suggests that the system is lightly damped.
% This results in sustained oscillations that take longer to settle, with moderate oscillatory dynamics.

% The third-order system (G4_elev3):
% Numerator: [0 0 0 0.0911]
% Denominator: [1.0000 3.1682 1.7900 4.0932]
% The third-order system captures a more detailed dynamic response, with three poles.
% The poles indicate a system that has more complex dynamics, including faster stabilization.
% The larger coefficients in the denominator suggest a stronger damping effect, especially with the real
% pole at 4.0932. This leads to a system that stabilizes more quickly, with less oscillatory behavior
% compared to the second-order system.
```

```
num1 =

         0         0    0.0916


denom1 =

    1.0438         0         0


num2 =

         0         0    0.0294


denom2 =

    1.0000    0.1538    1.3288


num3 =

         0         0         0    0.0911


denom3 =

    1.0000    3.1682    1.7900    4.0932
```



Question 6

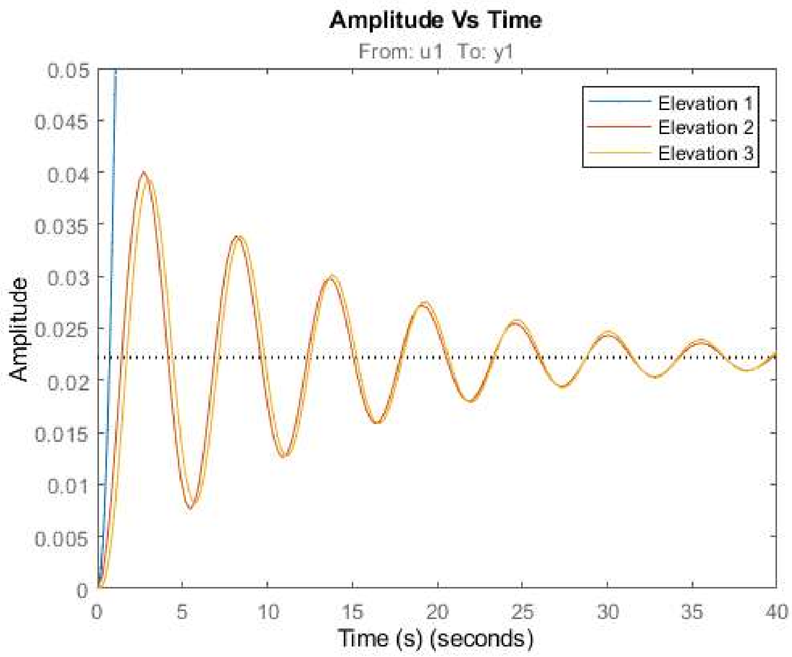
```
poles_elev2 = pole(G4_elev2)
poles_elev3 = pole(G4_elev3)

% The poles for elevation 2 are complex conjugates at -0.0769 +/- 0.1502i.
% These complex poles indicate that the system is second order, which
% typically results in an oscillatory response. The small real part of
% the poles suggests that the system has low damping, meaning the oscillations
% will decay slowly, resulting in a lightly damped system. This behavior
% implies that after a disturbance or input, the helicopter will oscillate
% in elevation before slowly stabilizing.

% For elevation 3, the system produces three poles: one real pole at -3.0239
% and two complex conjugate poles at -0.0722 +/- 1.1612i. Although there are
% three poles, the real pole is much farther from the origin in the left plane,
% meaning it decays rapidly and has minimal impact on the overall system behavior.
% The two complex poles dominate the system's behavior, causing it to act like
% a second-order system, similar to elevation 2.

% The real pole at -3.0239 contributes to faster initial stabilization due to its
% rapid decay. In the helicopter, this would correspond to a faster adjustment
% in response to inputs, such as changes in motor power, allowing the system to
% stabilize quicker before the oscillatory behavior governed by the complex poles
% takes over. As a result, during flight, the helicopter can adjust quickly and
% exhibit controlled oscillations before eventually stabilizing.
```

```
poles_elev2 =

  -0.0769 + 1.1502i
  -0.0769 - 1.1502i


poles_elev3 =

  -3.0239 + 0.0000i
  -0.0722 + 1.1612i
  -0.0722 - 1.1612i
```

Question 7

```
figure(2)
step(G4_elev1, G4_elev2, G4_elev3)
title('Amplitude Vs Time')
```

```
xlabel('Time (s)')
ylabel('Amplitude')
axis ([ 0 40, 0 0.05])
legend('Elevation 1', 'Elevation 2', 'Elevation 3')
```



Question 8

The voltage sum (V_sum) needed to make the helicopter hover at epsilon (ε) = 0 is essential because it determines the voltage required for steady level flight. This value allows for steady-state approximations, ensuring that the helicopter can maintain a stable altitude without ascending or descending.

When power is supplied to the motors, the helicopter begins to travel around the table, even though this power is primarily used to generate lift. The rotation occurs due to an uneven distribution of power supplied to each motor on either side of the helicopter. This imbalance results in a difference in the lift produced by each motor, creating an applied torque or rolling moment.

As a consequence, the helicopter rotates about its fixed axis, leading to circular motion around the table. Additionally, since the helicopter's motion is not fixed to any particular plane or axis, variations in motor power can cause it to drift and rotate during operation.

Conclusion

The helicopter model's dynamics were successfully analyzed through the derived transfer functions and step response simulations. The moment of inertia for the system was calculated to be J_e = 1.0438 kg-m^2, which indicates that the system's physical properties are within reasonable ranges for simulating helicopter movement. The calculated lift force, F_t = 0.7065 N, and the voltage needed for the system, V_sum = 5.0465 V, suggest that a moderate input is necessary to achieve stable lift.

In analyzing the step responses, the first-order system (Elevation 1) was found to be the most unstable, as it exhibited a tendency toward infinite elevation due to having two poles at the origin. This behavior signifies an unbounded response to input changes, indicating that it lacks the necessary damping to stabilize effectively.

On the other hand, the second-order system (Elevation 2) demonstrated lightly damped oscillations, with poles at -0.0769 ± 0.1502i, indicating moderate oscillatory behavior and slower settling times. In contrast, the third-order system (Elevation 3) showed a quicker response with a real pole at -3.0239, allowing it to stabilize more efficiently.

In summary, the results illustrate that higher-order models capture more complex dynamics, which lead to faster stabilization and a more accurate representation of the helicopter's response. This analysis highlights the critical importance of system parameters and order in affecting stability and control response, particularly noting that Elevation 1 was the most unstable configuration in the studied dynamics.

Published with MATLAB® R2021a